Year 1 Progress Report **Grant Numbers:** **BOP #44-164 (CPO)**
H8R2WRP-P00 (HMT)

Title: Improvement of a Multi-Instrument, Multi-Satellite Algorithm
For High-Resolution Pole-to-Pole Global Precipitation Analyses

Funding Agency: NOAA

Type of Report: Year 1 Progress Report

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Collaborators: NASA/GSFC/George Huffman, NWS/OHD/Wanru Wu

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Overall Project Objective:

To improve the CMORPH multi-satellite, multi-sensor global precipitation estimates for possible applications as a prototype GPM 'Day 1' product to cover the entire globe from pole to pole

Overall Project Methodology:

The project is organized into the following two tasks to achieve the overall project goal:

1) Improving the Kalman filter – based CMORPH technique; and
2) Developing a new technique to generate CONUS precipitation analyses of finer resolution for hydrological applications through combining information from the TRMM / GPM Level 3 global precipitation products and other sources;

Year 1 Accomplishments:

Substantial progress has been made on both tasks in the first year of this project. Major achievements include:

1) Completed the development of the Kalman filter based CMORPH for the construction of high-resolution satellite precipitation estimates from 60°S-60°N

Thanks to the joint support by NOAA Climate Program Office (CPO) and Hydrometeorology Testbed (HMT) over the previous funding cycle, we developed a conceptual model of Kalman Filter based CMORPH (KF-CMORPH). During the first year of this newly funded project, we continued our effort to refine the KF-CMORPH, completed the construction of an operational processing system for the KF-CMORPH and put the system on parallel run at a quasi-operational environment at NOAA Climate Prediction Center (CPC).

Major tasks involving the construction of the operational KF-CMORPH system include:

1a) Modifying the preprocessing module to take in PMW estimates from new instruments

We modified the preprocessing module of the CMORPH processing system so that it can take in passive microwave (PMW) based precipitation estimates from newly available SSMIS instruments aboard three polar orbiting satellites. Including PMW estimates from additional platforms improved the quantitative accuracy of the resulting CMORPH integrated high-resolution global precipitation estimates.

1b) Conducting a set of comprehensive experiments to examine the performance of the KF-CMORPH

We fine-tuned the KF-CMORPH algorithm to optimize its performance in producing high-resolution precipitation estimates with different availability of input satellite PMW and IR observations. In particular, we examined the best strategy to include the IR-based precipitation estimates and decided to use the IR estimates only when the gap between two consecutive PMW observations is 90 minutes or longer.

We then conducted a set of carefully designed experiments to examine the performance of the original and the KF-based CMORPH in depicting the spatial pattern, time variations, and probability density function (PDF) for precipitation with different intensities. The KF-based CMORPH presents consistently superior performance with improved pattern correlation and refined capability in retaining the PDF of precipitation intensity compared to the original CMORPH. The KF-CMORPH exhibits robust performance statistics in producing precipitation estimates where / when PMW observations are not available nearby, thanks to the incorporation of IR-based estimates (fig.1, 2). These results suggest that the KF-CMORPH is capable of generating precipitation estimates with improved quantitative accuracy and reasonable temporal homogeneity over the entire TRMM/GPM data period from 1998, over which availability of the PMW observations experienced substantial changes.

A paper describing the Kalman filter based CMORPH has been accepted for publication at the *Journal of Hydrometeorology*.

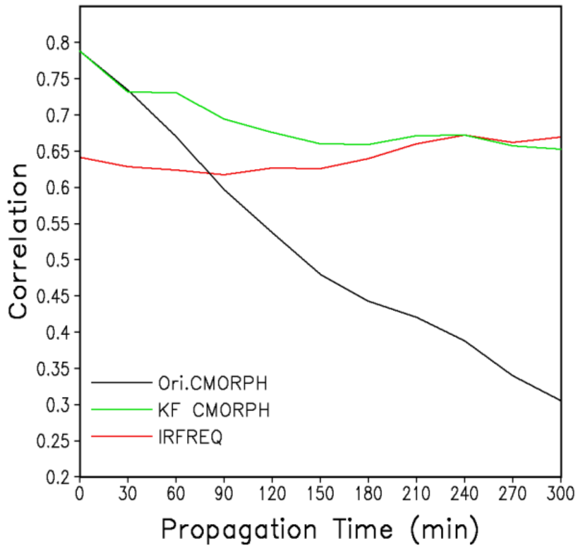

Fig.1:
Correlation between the combined microwave based precipitation estimates (MWCOMB) constructed from withdrawn independent LEO satellites and precipitation estimates derived from the IRFREQ (red), the original CMORPH (black) and the KF-CMORPH (green) using PMW observations from four LEO satellites. The MWCOMB is defined using the PMW estimates from the five LEO satellites not included in the creation of CMORPH analysis. Correlation is computed for 0.25°lat/lon 30-minute mean rain rates over the globe for July-August 2009.

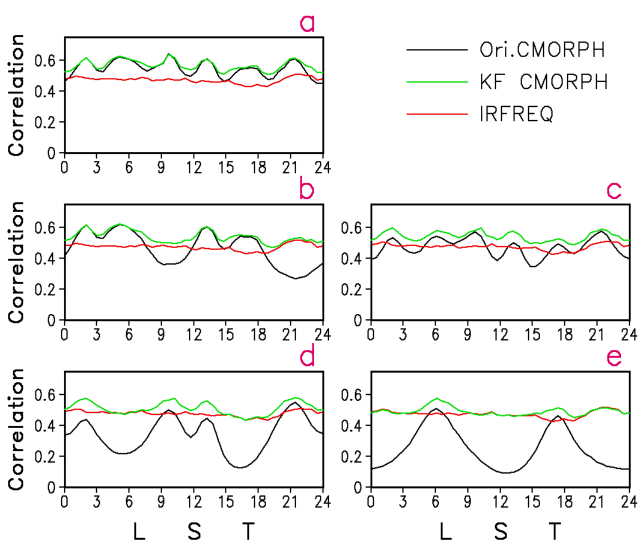

Fig.2:
Time series of correlation of (red) KF-CMORPH, (green) operational CMORPH, and (dark blue) IR-estimates at the target time and (light blue) 30-min after the target time, compared against Q2 radar observations for each of the 48 half hour periods within a day. Comparisons are performed for 30-min precipitation averaged on a 0.25°lat/lon grid over CONUS.

1c) Transferring the CMORPH processing system to NASA/GSFC

This project is part of NOAA's contribution to the Global Precipitation Measurement (GPM) project. The PI and the Co-I of this project are core members of a team in charge of the development of a US unified algorithm for the GPM Day-1 Level 3 global precipitation products. The CMORPH technique being developed at NOAA Climate Prediction Center (CPC) with supports from NOAA/CPO and USWRP/HMT consists of the primary component of the US GPM Level 3 merged precipitation algorithm.

During the first year of this project, we have transferred the processing system based on the original CMORPH algorithm to the NASA/GPM team led by Dr. George J. Huffman, a collaborator of this project. The system is now under parallel run at a quasi-operational environment at NASA/GSFC.

In association with this system transfer, the PI and the Co-I of this project participated in the drafting of a technical document (Algorithm Theoretical Basis Document, ATBD) for the GPM integrated multi-satellite merged precipitation estimates.

2) Started the development work to extend the CMORPH high-resolution precipitation estimates to cover the entire globe from pole-to-pole

We have started our development work to enhance the Kalman filter based CMORPH for the construction of high-resolution precipitation over the entire globe from pole to pole. We have collected both the IR and PMW observations from all available low earth orbit (LEO) platforms for a two-month test period from July-August, 2009. We produced composite PMW and IR observations maps in a 30-min interval and on an 8kmx8km grid over the globe using all available LEO data (fig.3). We then examined the availability and quality of these satellite observations in representing precipitation estimates over the mid- and hi-latitudes. Preliminary results showed that the current generation PMW-based precipitation estimates are not capable of catching snowfall over cold surface (fig.4). New techniques therefore need to be developed to derive cold season precipitation estimates from other sources of information, including satellite IR observations and numerical model simulations.

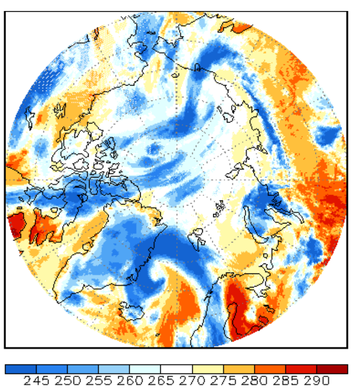

Fig.3:
Six-hourly[12-18 UTC,21 August, 2009] mean blackbody temperature (TB) composited from IR observations of all available low earth orbit (LEO) satellites.

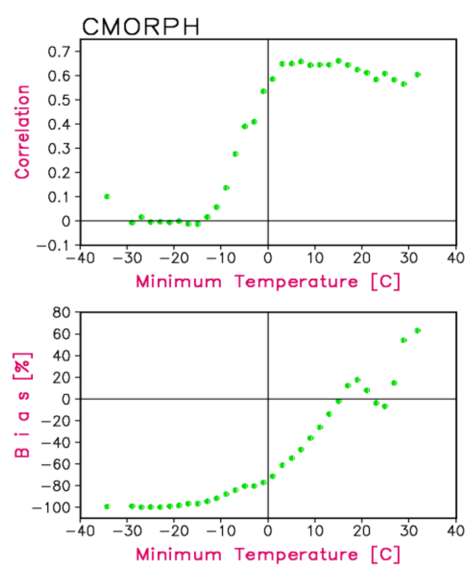

Fig.4:
(top) Correlation and (bottom) bias between the CMORPH daily precipitation estimates derived from PMW observations and the CPC gauge-based daily precipitation analysis. The statistics are calculated as a function of minimum surface air temperature. Bias for the satellite estimates are defined relative to the gauge-based analysis.

3) **Completed the construction of an operational system to remove CMORPH Bias over the global land through PDF matching with gauge data**

In the first year of this project, we have completed the construction of an operational processing system to remove the biases in the CMORPH satellite precipitation estimates through comparison with concurrent gauge observations. This system is constructed based on the development work we performed during the last funding cycle with support from NOAA/CPO and USWRP/HMT. In performing bias correction for CMORPH precipitation estimates over a target grid box of 0.25^{o}lat/lon, co-located data pairs of CMORPH and gauge observations are collected over a spatial / time domain centering at the target grid box. Probability density function (PDF) of daily CMORPH is then constructed and matching against that of the daily gauge data to remove the CMORPH biases.

In our operational system, the CMORPH bias is corrected in two steps as illustrated in fig.5. First, the bias correction is performed using PDF tables constructed from historical data from 2001-2009. PDF tables are created for each 0.25^{o}lat/lon grid box over land for each calendar day using data over a 31-day period centering at the target calendar day and over a spatial domain surrounding the target grid box. The spatial domain is expanded until sufficient number of data pairs (>500) are collected to ensure stable PDF tables. Through the use of historical data, the PDF tables can be created using data over a relatively small spatial domain, reducing the scale of remaining biases.

A second step is implemented to repeat the PDF matching procedure using data pairs collected from the satellite and gauge data over a 30-day period ending at the target data. This step is designed to reduce the year-to-year variations of the biases remaining in the CMORPH after the correction in the first step.

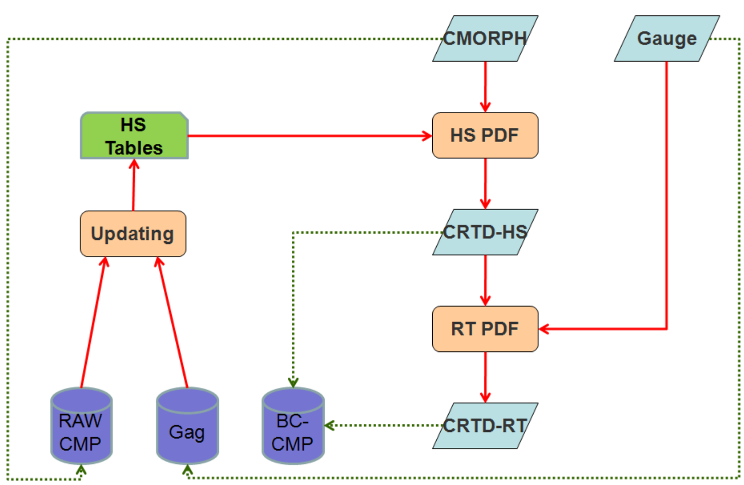

Fig.5: Flow chart of the operational processing system for CMORPH bias correction over global land.

The system has been installed on a quasi-operational IT environment at NOAA Climate Prediction Center (CPC) and will be migrated to a NCEP Central Operation (NCO) operational system (the Compute Farm) pending permission.

The preliminary version of the bias corrected CMORPH has been produced for a 13-year period using the operational system described above and applied to examine global precipitation and their representation in global models. As illustrated in fig.6, the high-resolution precipitation data set provided us with powerful tool to examine global precipitation variations of a wide range of time / space scales, from meso- (hourly / 25km) to climate.

A paper describing the conceptual model of the CMORPH correction and optimal combination of bias-corrected CMORPH and gauge observations has been accepted for publication at *J. Geophys. Res.* In addition, the PI published an article at the *AGU Hydrology News Letter* reviewing the history and current status of efforts to integrate information from multiple sources for the improved precipitation products.

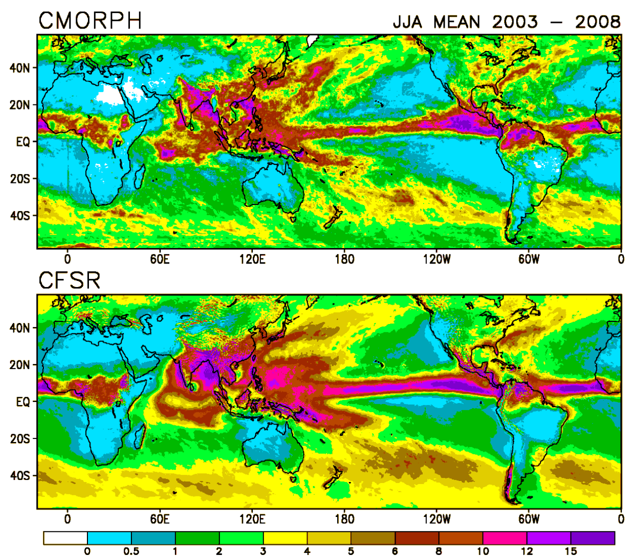

Fig.6:
2003-2008 five year mean June-July-August precipitation (mm/day) derived from (top) the bias-corrected CMORPH satellite observations and (bottom) NCEPCFS reanalysis.

Expected Accomplishments for Project Year 2

During the second year of this project, we will start working on the development of a prototype algorithm of the Kalman Filter based CMORPH for the generation of global precipitation estimates from pole to pole and a new technique to integrate satellite estimates with additional regional information for a regional precipitation estimates with refined spatial resolution and quantitative accuracy.

a) **Developing CMORPH-based techniques to generate precipitation estimates from pole to pole**

Our plan for the next project year includes:

- Developing new technique to estimate cold season precipitation through combined use of satellite IR and PMW observations

- Exploring best strategy to compute cloud advection vectors over high latitudes;

- Examine the best strategy to incorporate information from numerical models; and

- Construct a prototype algorithm for the production of high-resolution precipitation estimates over mid- and high latitudes through integrating information from multiple sources

b) Combining global CMORPH with gauge observations and other regional information

Specific work includes:

- Developing a prototype model to combine CMORPH with hourly gauge analysis over CONUS;
- Examining radar observations and their application in the merging processes; and
- Developing a prototype model to construct regional precipitation analysis at a very high resolution (4km/hourly) by combining information from gauge measurements, radar observations and satellite estimates.

Publications and Presentations:

Publications:

Joyce, R.J., and P. Xie, 2011: Kalman Filter based CMORPH. *J. Hydrometeor*., (in press)

Xie, P., and A.-Y. Xiong, 2011: A Conceptual Model for Constructing High-Resolution Gauge – Satellite Merged Precipitation Analyses. *J. Geophys. Rev*., (accepted)

Xie, P., and Y. Hong, 2011: Integrating Information from Multiple Sources for Improved Precipitation Products. *AGU Hydrology Newsletter*, (in press)

Presentations

Joyce, R., P. Xie, and S. Yoo 2010: Kalman-Filtered CMORPH using TRMM to Blend Satellite Rainfall. *5th International Precipitation Working Group Meeting*, October 11-15, 2010. Hamburg, Germany.

Joyce, R., P. Xie, and S. Yoo 2010: A Bias-Corrected Kalman Filter Based High-Resolution Global Precipitation Analysis, *PMM Science Team Meeting*, 1-4 November, Seattle, Washington.

Xie, P., R. Joyce, and S. Yoo 2010: Recent Progress with Kalman Filter CMORPH (PI-poster), *PMM Science Team Meeting*, 1-4 November, Seattle, Washington.

Xie, P., S.-H. Yoo, R.J. Joyce, and Y. Yarosh, 2010: A high-resolution gauge-satellite merged global precipitation analysis and its applications for model verifications. *WMO 3rd International Conf. on QPE/QPF*. Oct. 17-20, 2010, Nanjing, CHINA.

Xie, P., S.-H. Yoo, R.J. Joyce, and Y. Yarosh, 2011: A multi-sensor merged analysis of high-resolution global precipitation. 25th AMS Conf. on Hydrology, Jan.24 – 28, 2011, Seattle, WA.

Xie, P., S.-H. Yoo, R.J. Joyce, and Y. Yarosh, 2011: Bias-corrected CMORPH: A 13-year analysis of high-resolution global precipitation. *2011 EGU Annual Science Assembly*, April 4 -8, 2011, Vienna, Austria.

Xu, B., and P. Xie, 2010: Quantifying error in the CMORPH satellite precipitation estimates. *2010 AGU Annual Science Assembly*. Dec.13-17, 2010, San Francisco, CA.

Yoo, S.-H. and P. Xie, 2010: Combining High-Resolution Satellite Estimates with Gauge Observations. *5th International Precipitation Working Group Meeting*, 11-15 October in Hamburg, Germany.

Yoo, S.-H., P. Xie, and W. Wang, 2010: Diurnal cycle of precipitation in the observation and CFS reanalysis. 35th Climate Diagnostics and Prediction Workshop, 4-7 October in Raleight, North Carolina.

Yoo, S.-H., P. Xie, and W. Wang, 2011: Global precipitation diurnal variations depicted in the observation and the CFS Reanalysis. 91th AMS Annual Meeting, 23-27 January in Seattle, Washington.

Invited Seminars:

Xie, P., 2010: High-resolution global precipitation analyses for improved applications in weather, climate, and hydrometeorology. Presented at *Department of Atmospheric Sciences, UIUC*, on Sept.1, 2010.

Xie, P., 2011: A gauge – satellite merged analysis of high-resolution global precipitation. Presented at NASA/GSFC on Mar.30, 2011, as part of the NOAA Climate Testbed (CTB) seminar series.